Cost Saving Strategies: Using a Project Planning Process That Can Integrate Capital and Operational Spending Into a Nanofabrication Business Plan

A. Gregg and M. Strnad

Abbie Gregg, Inc.
1130 East University Drive, Suite 105, Tempe, Arizona 85281, USA
agregg@abbiegregg.com, mstrnad@abbiegregg.com

ABSTRACT

AGI will show how a project planning process that includes a business case analysis for Nanofabrication buildings can help with many of the design, construction and operational decisions for the buildings. The typical building project often focuses only on capital costs and timing. Items such as the costs of the equipment, cost of the building, and a general timeline are often considered. However, how the building design can affect the equipment start up process and ongoing operating costs are often overlooked. Items such as facilities cost, equipment maintenance, consumables, product yield, and personnel need to be considered to realistically evaluate the alternatives. AGI will illustrate several examples using a computer program (AGI's CARME model) to calculate a high-level income and expense model. AGI's Jupiter model can then be used to get into specific operational costs. By using both models, tradeoffs can be evaluated to optimize the long and short term costs of running a facilities and building product.

Attendees will learn how to uses the two models to analyze the income and expenses for a Nanofabrication Operation, how to use these analyses to make decisions on design, construction and operational strategies, and how to forecast product costs under a variety of circumstances.

1 INTRODUCTION

Developing an in-depth business plan that considers all the details of both capital and operational costs is critical to the success of a Nanofabrication start-up. Overlooking some of these details can cause significant cost surprises as the start-up proceeds. A good cost model can allow quick analysis of several what-if scenarios and identify what the best solutions are.

1.1 The Need for Models

The typical manufacturing startup or expansion requires a capacity study and cost model to establish tool set, facility space, staffing and material requirements. These need to be rolled up as product costs and overall project budget.

The typical research center also needs to determine both start up and operating costs for the center, including facilities and campus services, equipment, consumables, and personnel.

1.2 How to Use a Model

Metrics to analyze product and project costs for various manufacturing scenarios allow the user to determine scale up strategies for the required resources.

Metrics to analyze the income and expenses for research centers, how to use these analyses to make decisions on design, construction and operational strategies, and how to determine hourly recharge rates or cost per unit under a variety of circumstances.

1.3 Why do Models?

A good model can be used to quickly review and revise options. It will enable the user to understand which variable have the most significant impact. The model can be used to plan capital, facility size, and staffing levels. Using the model you can forecast necessary spending and predict the cost per unit. Some examples of the basic unit in this case include per device, per square inch, or per research hour.

1.4 Typical Levels of Detail

The usefulness of a model is often determined by how much data is available or can be forecast. The better the data input into the model, the better the output.

The basic model is more typical for a high level view of a 'concept' project, such as building a lab to be used for research. Often the specific process or products are not well defined until the center is well under construction and the actual researchers who will use the facility have obtained necessary grants or funding.

The complex model is used for a detailed view of a well defined or specific project application such as building 4GB memory devices. Details such as specific tools, throughput and process cycle times are already well understand or can be forecast.

Each has a place in the modeling world. Choosing the right approach means considering what is known and what is not known when building the model. The next two sections will explain the difference between the two types.

2 A BASIC COST MODEL - CARME

CARME was designed to provide a high level view for applications such as University Laboratories and Research and Development Centers.

2.1 CARME Model Inputs

To build a successful CARME model you will need to provide:

- Equipment set
  - Generic tool type
  - Estimated cost per tool
- Total square footage
  - How big is the lab going to be?
- Materials per month or year
  - Estimated usage of the gases and chemicals for the lab
- Headcount in total
  - What is the forecast staffing?
- User hours per month or year
  - How will the lab be used?
  - Who will be using it?
  - Charge by tool usage?
  - Charge by lab space usage?
  - Charge by personnel support required?

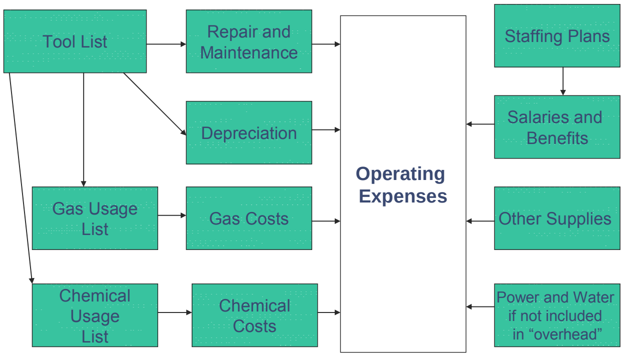


Figure 1 – CARME Data Flow

2.2 Developing The CARME Model

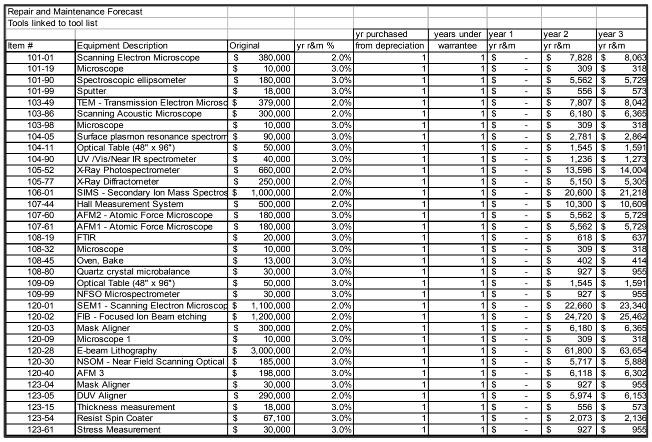
The CARME model works very well for a center that is preliminary research based. It uses a relatively simple database. It requires much less time investment to develop when compared to a complex model.

The output of the model will be a high level operation plan. It will provide cost per user hour or unit produced. It will also allow the user to input various funding source options.

The assumptions in the model include a list of the items that are the basis of the model such as usage hours, cost ratios, inflation rate, and overhead .These items need to be reviewed and updated as the operation becomes better defined.

2.3 CARME Model Specifics

- Tool List
  - Depreciation
  - Repair and Maintenance
    - This lists the original price of the tools used in the operation.
    - A tool's original price drives the depreciation (based on the year of purchase and the number of years the tool is depreciated over). The model allows for equipment charged to other projects that do not add to the calculated depreciation.
    - Repair and Maintenance costs are also calculated using a historical percentage of original cost, inflation, and considering any vendor contracts.



Repair and Maintenance Forecast
Tools linked to tool list

				yr purchased	years under	year 1	year 2	year 3
Item #	Equipment Description	Original	yr r&m %	from depreciation	warrantee	yr r&m	yr r&m	yr r&m
101-01	Scanning Electron Microscope	$ 380,000	2.0%	1	1	$ -	$ 7,828	$ 8,063
101-19	Microscope	$ 10,000	3.0%	1	1	$ -	$ 309	$ 318
101-90	Spectroscopic ellipsometer	$ 180,000	3.0%	1	1	$ -	$ 5,562	$ 5,729
101-99	Sputter	$ 18,000	3.0%	1	1	$ -	$ 556	$ 573
103-49	TEM - Transmission Electron Microsc	$ 379,000	2.0%	1	1	$ -	$ 7,807	$ 8,042
103-86	Scanning Acoustic Microscope	$ 300,000	2.0%	1	1	$ -	$ 6,180	$ 6,365
103-98	Microscope	$ 10,000	3.0%	1	1	$ -	$ 309	$ 318
104-05	Surface plasmon resonance spectrom	$ 90,000	3.0%	1	1	$ -	$ 2,781	$ 2,864
104-11	Optical Table (48" x 96")	$ 50,000	3.0%	1	1	$ -	$ 1,545	$ 1,591
104-90	UV /Vis/Near IR spectrometer	$ 40,000	3.0%	1	1	$ -	$ 1,236	$ 1,273
105-52	X-Ray Photospectrometer	$ 660,000	2.0%	1	1	$ -	$ 13,596	$ 14,004
105-77	X-Ray Diffractometer	$ 250,000	2.0%	1	1	$ -	$ 5,150	$ 5,305
106-01	SIMS - Secondary Ion Mass Spectros	$ 1,000,000	2.0%	1	1	$ -	$ 20,600	$ 21,218
107-44	Hall Measurement System	$ 500,000	2.0%	1	1	$ -	$ 10,300	$ 10,609
107-60	AFM2 - Atomic Force Microscope	$ 180,000	3.0%	1	1	$ -	$ 5,562	$ 5,729
107-61	AFM1 - Atomic Force Microscope	$ 180,000	3.0%	1	1	$ -	$ 5,562	$ 5,729
108-19	FTIR	$ 20,000	3.0%	1	1	$ -	$ 618	$ 637
108-32	Microscope	$ 10,000	3.0%	1	1	$ -	$ 309	$ 318
108-45	Oven, Bake	$ 13,000	3.0%	1	1	$ -	$ 402	$ 414
108-80	Quartz crystal microbalance	$ 30,000	3.0%	1	1	$ -	$ 927	$ 955
109-09	Optical Table (48" x 96")	$ 50,000	3.0%	1	1	$ -	$ 1,545	$ 1,591
109-99	NFSO Microspectrometer	$ 30,000	3.0%	1	1	$ -	$ 927	$ 955
120-01	SEM1 - Scanning Electron Microscop	$ 1,100,000	2.0%	1	1	$ -	$ 22,660	$ 23,340
120-02	FIB - Focused Ion Beam etching	$ 1,200,000	2.0%	1	1	$ -	$ 24,720	$ 25,462
120-03	Mask Aligner	$ 300,000	2.0%	1	1	$ -	$ 6,180	$ 6,365
120-09	Microscope 1	$ 10,000	3.0%	1	1	$ -	$ 309	$ 318
120-28	E-beam Lithography	$ 3,000,000	2.0%	1	1	$ -	$ 61,800	$ 63,654
120-30	NSOM - Near Field Scanning Optical	$ 185,000	3.0%	1	1	$ -	$ 5,717	$ 5,888
120-40	AFM 3	$ 198,000	3.0%	1	1	$ -	$ 6,118	$ 6,302
123-04	Mask Aligner	$ 30,000	3.0%	1	1	$ -	$ 927	$ 955
123-05	DUV Aligner	$ 290,000	2.0%	1	1	$ -	$ 5,974	$ 6,153
123-15	Thickness measurement	$ 18,000	3.0%	1	1	$ -	$ 556	$ 573
123-54	Resist Spin Coater	$ 67,100	3.0%	1	1	$ -	$ 2,073	$ 2,136
123-61	Stress Measurement	$ 30,000	3.0%	1	1	$ -	$ 927	$ 955

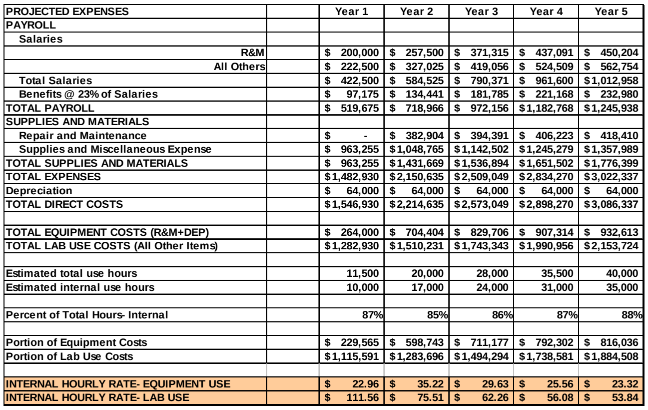
Figure 2 – CARME Tool R&M Data

- Gas Usage
  - Gas Costs
    - Estimates of the total gas usage for the operation
    - This number drives an annual usage and an annual cost for each gas.
- Chemical Usage
  - Chemical Costs
    - Estimates of the total chemical usage for the operation
    - This number drives an annual usage and an annual cost for each chemical.
- Staffing Plans
  - Salaries and Benefits
    - List the annual staffing plan for the operation.
    - It also lists the average salary for each of the positions.
    - The model also allows for headcount that does not have to be funded by the center.
- Other supplies
    - All supplies (other than gas and chemicals) are accounted for.
    - Electricity is based on estimated usage and rates.
    - DI Water is based on cost of operating the DI water system.

- Minor facilities work is charged to the center.
- Major facilities work is funded through the site facilities operation.

2.4 CARME Model Output

- Rates and Income Statement
  - Rolls up all the costs and determines an hourly equipment and tool charge rate for both internal and external users.
  - Graphs of the internal and external rates are provided.
  - A combined income statement is also provided.



PROJECTED EXPENSES		Year 1	Year 2	Year 3	Year 4	Year 5
PAYROLL						
Salaries						
R&M		$ 200,000	$ 257,500	$ 371,315	$ 437,091	$ 450,204
All Others		$ 222,500	$ 327,025	$ 419,056	$ 524,509	$ 562,754
Total Salaries		$ 422,500	$ 584,525	$ 790,371	$ 961,600	$1,012,958
Benefits @ 23% of Salaries		$ 97,175	$ 134,441	$ 181,785	$ 221,168	$ 232,980
TOTAL PAYROLL		$ 519,675	$ 718,966	$ 972,156	$1,182,768	$1,245,938
SUPPLIES AND MATERIALS						
Repair and Maintenance		$ -	$ 382,904	$ 394,391	$ 406,223	$ 418,410
Supplies and Miscellaneous Expense		$ 963,255	$1,048,765	$1,142,502	$1,245,279	$1,357,989
TOTAL SUPPLIES AND MATERIALS		$ 963,255	$1,431,669	$1,536,894	$1,651,502	$1,776,399
TOTAL EXPENSES		$1,482,930	$2,150,635	$2,509,049	$2,834,270	$3,022,337
Depreciation		$ 64,000	$ 64,000	$ 64,000	$ 64,000	$ 64,000
TOTAL DIRECT COSTS		$1,546,930	$2,214,635	$2,573,049	$2,898,270	$3,086,337
TOTAL EQUIPMENT COSTS (R&M+DEP)		$ 264,000	$ 704,404	$ 829,706	$ 907,314	$ 932,613
TOTAL LAB USE COSTS (All Other Items)		$1,282,930	$1,510,231	$1,743,343	$1,990,956	$2,153,724
Estimated total use hours		11,500	20,000	28,000	35,500	40,000
Estimated internal use hours		10,000	17,000	24,000	31,000	35,000
Percent of Total Hours- Internal		87%	85%	86%	87%	88%
Portion of Equipment Costs		$ 229,565	$ 598,743	$ 711,177	$ 792,302	$ 816,036
Portion of Lab Use Costs		$1,115,591	$1,283,696	$1,494,294	$1,738,581	$1,884,508
INTERNAL HOURLY RATE- EQUIPMENT USE		$ 22.96	$ 35.22	$ 29.63	$ 25.56	$ 23.32
INTERNAL HOURLY RATE- LAB USE		$ 111.56	$ 75.51	$ 62.26	$ 56.08	$ 53.84

Figure 3 – Typical CARME Rate Calculations

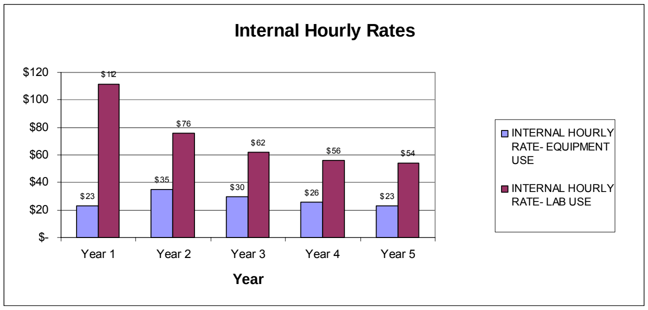


Figure 4 – CARME Rate Output Graph

2.5 CARME has been used to determine the following:

- Reasonable tool set to provide for the lab vs. providing space for tools provided by programs
- Importance of negotiating long term service contracts at time of tool purchase, within capital budgets, to avoid operating cost impact during early years of the center's operation
- Realistic ramp of user hours and the impact on hourly cost
- Need for subsidizing certain staff or equipment with specific funding

3 A COMPLEX COST MODEL- JUPITER

The Jupiter model was designed to provide very detailed forecast of facilities built to provide a specific type of product output.

3.1 Jupiter Model – some key questions

- How well is supply chain defined?
- In house or foundry work?
- Do the items following exist?
  - Bill of Materials (BOM)
  - Process Specs
  - Detailed Flow
  - Detailed Tool set
  - Layout and equipment Sizing

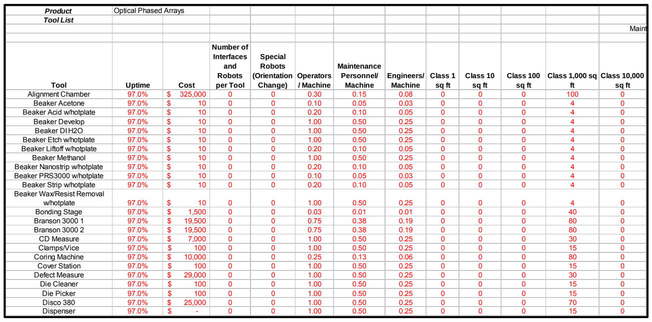
3.2 Jupiter Model Inputs

- Very specific process flow
  - What steps are needed?
  - In what sequence?

Product	Product ABC			
Model	Final As-built			
Step	**Operation**	**Tool**	**Recipe**	**Detailed Operation Description**
1.1	Initial Wafer Cleaning	Manual Carry	Incoming Material OPA	Inspect thickness (0.12" thick)
1.2	Initial Wafer Cleaning	Manual Scribe	Scribe	Scribe front side with ID #
1.3	Initial Wafer Cleaning	Manual Clean	Clean Substrate - Liquinox	Clean substrate in liquinox with gloved hands, rinse in DI water.
1.4	Initial Wafer Cleaning	Beaker Nanostrip w/hotplate	Nanostrip Clean OPA	Nanostrip clean @ 50C for > 15 min., flush rinse in DI H2O for > 15 min
1.5	Initial Wafer Cleaning	Beaker Acid w/hotplate	Clean Substrate - Acid	Clean in 1:1:1 H2O:HCl:H2O2 @50C for >15 min.
1.6	Initial Wafer Cleaning	Beaker Methanol	Methanol Soak OPA	Cover beaker with foil until ready to proceed to step 2.1
2.1	Al Deposition (Align Marks)	N2 Tube	Retrieve Wafer	Retrieve wafer from methanol beaker and blow dry with N2
2.2	Al Deposition (Align Marks)	Branson 3000 1	O2 Plasma OPA	5 min O2 plasma 400W 1.5 Torr
2.3	Al Deposition (Align Marks)	Perkin Elmer 4400	Deposit Al Cu	Deposit 1000 A Al(1%) Cu on substrate front side using PE 4400
3.1	Alignment Guide Photo	YES8	HMDS Prime	HMDS Prime; allow wafers to cool
3.2	Alignment Guide Photo	SVG Track 2	Coat/Bake AZ1512	Coat/Bake AZ1512 Resist (t=1.5 micron meter) on front SVG track
3.3	Alignment Guide Photo	Wet Box	Hydrate	Hydrate 15 min minimum in room air
3.4	Alignment Guide Photo	Perkin Elmer 340	Align	T36 Align Photomask (light field)
3.5	Alignment Guide Photo	SVG Track 1	Bake	Post exposure bake on front SVG track
3.6	Alignment Guide Photo	Beaker Develop	Immersion Develop	Immersion develop 60 sec AZ300MIF developer
3.7	Alignment Guide Photo	Nikon Microscope	Inspect - Development	Inspect for complete development of alignment pattern
3.8	Alignment Guide Photo	SVG Track 1	Bake	Hard bake on front SVG track, 60 sec. 112C
3.9	Alignment Guide Photo	Branson 3000 1	O2 Plasma OPA	O2 Plasma Descum, 5 min. O2 plasma at 400W 1.5 Torr
4.1	Alignment Guide Etch	Beaker Etch w/hotplate	Etch Al	Etch Al in 100% solution of Aluminum etchant at 40C
4.2	Alignment Guide Etch	Microscope w/video	Inspect - Etch	Inspect for complete etching of Al
4.3	Alignment Guide Etch	Beaker Acetone	Strip Resist - Acetone	Strip resist in Acetone, rinse in methanol, H2O, finish in rinser/drier
4.4	Alignment Guide Etch	CD Measure	Inspect - Alignment	Inspect alignment guides for undercutting duimg Al etching, CD measure
4.5	Alignment Guide Etch	Defect Measure	Inspect - Aperture	Inspect Aperture area for residual Al, defect measure
5.1	Front Side Films	Manual Clean	Clean Substrate - Liquinox	Clean substrate in liquinox with gloved hands, rinse in DI water
5.2	Front Side Films	Beaker Methanol	Rinse Substrate - Methanol OPA	Rinse substrate in methanol, blow dry N2
5.3	Front Side Films	Sunnex Lamp	Inspect - Particulates OPA	Inspect substrate for particulates in specular reflection using Sunnex Lamp
5.4	Front Side Films	Branson 3000 1	O2 Plasma OPA	5 min O2 plasma 400W 1.5 Torr
5.5	Front Side Films	Spector	Al203 Dep	IBSD (SPECTOR) Al2O3 on front side, using program OCSW AL2O3

Figure 5 – Jupiter Process Flow

- Specific recipes
  - What tools?
  - How long per step?
  - Yield per step?
  - How many operators?
  - What materials are required?
- Equipment set
  - What tool?
  - Cost?
  - Size?
  - Throughput?
  - Uptime?



Product	Optical Phased Arrays											
Tool List												
												Maint
Tool	**Uptime**	**Cost**	**Number of Interfaces and Robots per Tool**	**Special Robots (Orientation Change)**	**Operators / Machine**	**Maintenance Personnel/ Machine**	**Engineers/ Machine**	**Class 1 sq ft**	**Class 10 sq ft**	**Class 100 sq ft**	**Class 1,000 sq ft**	**Class 10,000 sq ft**
Alignment Chamber	97.0%	$ 325,000	0	0	0.30	0.15	0.08	0	0	0	100	0
Beaker Acetone	97.0%	$ 10	0	0	0.10	0.05	0.03	0	0	0	4	0
Beaker Acid w/hotplate	97.0%	$ 10	0	0	0.20	0.10	0.05	0	0	0	4	0
Beaker Develop	97.0%	$ 10	0	0	1.00	0.50	0.25	0	0	0	4	0
Beaker DI H2O	97.0%	$ 10	0	0	1.00	0.50	0.25	0	0	0	4	0
Beaker Etch w/hotplate	97.0%	$ 10	0	0	1.00	0.50	0.25	0	0	0	4	0
Beaker Liftoff w/hotplate	97.0%	$ 10	0	0	0.20	0.10	0.05	0	0	0	4	0
Beaker Methanol	97.0%	$ 10	0	0	1.00	0.50	0.25	0	0	0	4	0
Beaker Nanostrip w/hotplate	97.0%	$ 10	0	0	0.20	0.10	0.05	0	0	0	4	0
Beaker PRS3000 w/hotplate	97.0%	$ 10	0	0	0.10	0.05	0.03	0	0	0	4	0
Beaker Strip w/hotplate	97.0%	$ 10	0	0	0.20	0.10	0.05	0	0	0	4	0
Beaker Wax/Resist Removal w/hotplate	97.0%	$ 10	0	0	1.00	0.50	0.25	0	0	0	4	0
Bonding Stage	97.0%	$ 1,500	0	0	0.03	0.01	0.01	0	0	0	40	0
Branson 3000 1	97.0%	$ 19,500	0	0	0.75	0.38	0.19	0	0	0	80	0
Branson 3000 2	97.0%	$ 19,500	0	0	0.75	0.38	0.19	0	0	0	80	0
CD Measure	97.0%	$ 7,000	0	0	1.00	0.50	0.25	0	0	0	30	0
Clamps/Vice	97.0%	$ 100	0	0	1.00	0.50	0.25	0	0	0	15	0
Coring Machine	97.0%	$ 10,000	0	0	0.25	0.13	0.06	0	0	0	80	0
Cover Station	97.0%	$ 100	0	0	1.00	0.50	0.25	0	0	0	15	0
Defect Measure	97.0%	$ 29,000	0	0	1.00	0.50	0.25	0	0	0	30	0
Die Cleaner	97.0%	$ 100	0	0	1.00	0.50	0.25	0	0	0	15	0
Die Picker	97.0%	$ 100	0	0	1.00	0.50	0.25	0	0	0	15	0
Disco 380	97.0%	$ 25,000	0	0	1.00	0.50	0.25	0	0	0	70	0
Dispenser	97.0%	$ -	0	0	1.00	0.50	0.25	0	0	0	15	0

Figure 6 – Jupiter Tool Data

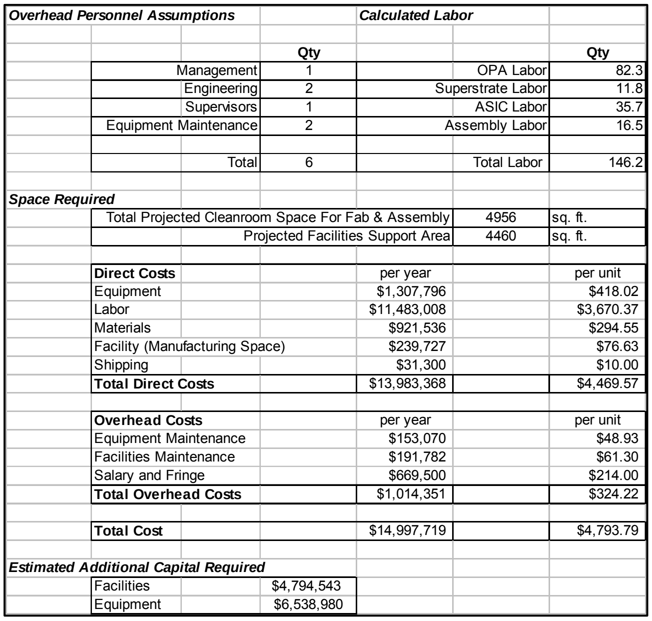
- Layouts
    - Clean room class
    - Facilities support space

3.3 Developing the Model

Developing a Jupiter model requires extensive research, building a large database and a significant time investment. However, the detailed cost data it provides is critical for planning a complex operation.

3.4 Model Output

The Jupiter model provides detailed results down to cost per unit (wafer, module, die, etc.). It can easily be used to determine bottleneck operation or tools. It can be used to show return on investment for any incremental investments.



Overhead Personnel Assumptions				***Calculated Labor***		
			Qty			**Qty**
		Management	1		OPA Labor	82.3
		Engineering	2		Superstrate Labor	11.8
		Supervisors	1		ASIC Labor	35.7
		Equipment Maintenance	2		Assembly Labor	16.5
		Total	6		Total Labor	146.2
Space Required						
	Total Projected Cleanroom Space For Fab & Assembly				4956	sq. ft.
	Projected Facilities Support Area				4460	sq. ft.
	Direct Costs			per year		per unit
	Equipment			$1,307,796		$418.02
	Labor			$11,483,008		$3,670.37
	Materials			$921,536		$294.55
	Facility (Manufacturing Space)			$239,727		$76.63
	Shipping			$31,300		$10.00
	Total Direct Costs			$13,983,368		$4,469.57
	Overhead Costs			per year		per unit
	Equipment Maintenance			$153,070		$48.93
	Facilities Maintenance			$191,782		$61.30
	Salary and Fringe			$669,500		$214.00
	Total Overhead Costs			$1,014,351		$324.22
	Total Cost			$14,997,719		$4,793.79
Estimated Additional Capital Required						
	Facilities		$4,794,543			
	Equipment		$6,538,980			

Figure 7 – Jupiter Output

3.5 Jupiter has been used to determine the following:

- Modeled ramping from ‘R&D’ volumes up to ‘Production’ quantities
- Compared costs of 1, 2, and 3 shift staffing versus capital investment for extra tools at bottlenecks
- Compared ‘in house’ space costs versus leasing ‘outside’ space for expansion

4 SUMMARY

Cost models are a useful part of the planning process. They can be used to:

- Establish / benchmark recharge rates and costs
- Clearly analyze bottlenecks and how to break them
- Justify and propose complex staff and equipment funding plans over time
- Respond to capacity / cost inquiries from potential users
- Create annual operating budget and modify based on measured results
- They are useful not only for Manufacturing, but also useful for “Center,” “Foundry” and “Shared” user facilities.